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Helms et al.

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(54) **MODULAR HOUSING FOR A ROTARY STEERABLE TOOL**

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E21B 47/024 (2006.01)

(52) **U.S. Cl.** **175/76**; 175/61; 175/45; 175/325.3; 175/24

(58) **Field of Classification Search** 175/24, 175/61, 76, 325.3, 325.5, 45
See application file for complete search history.

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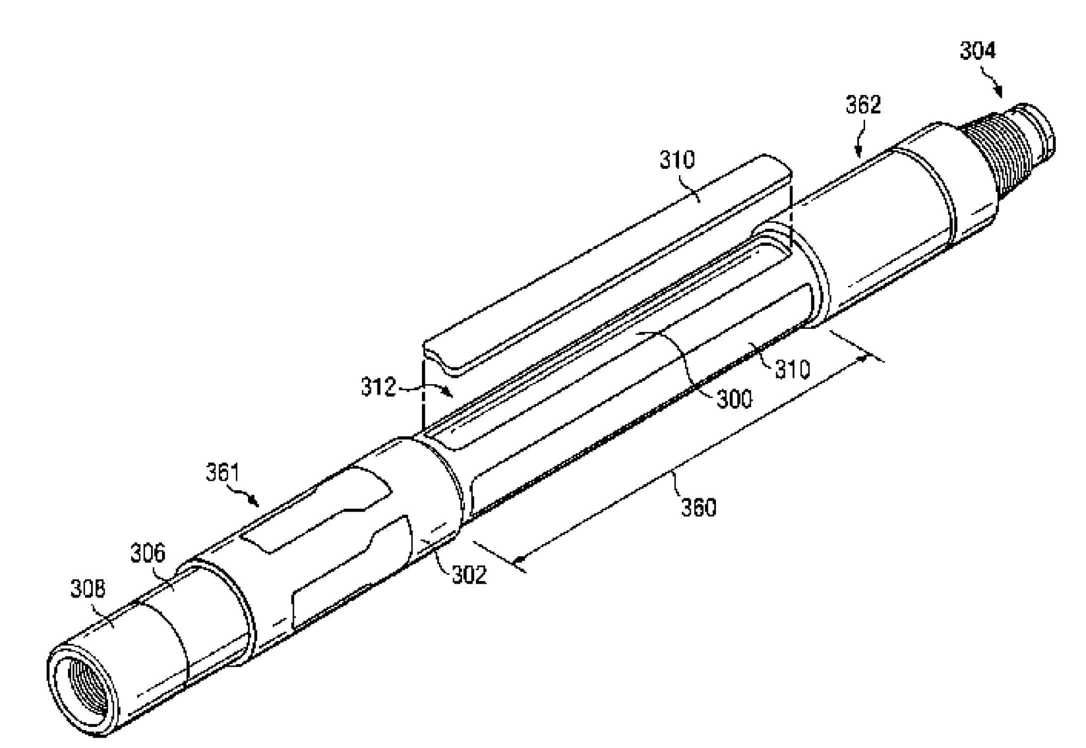
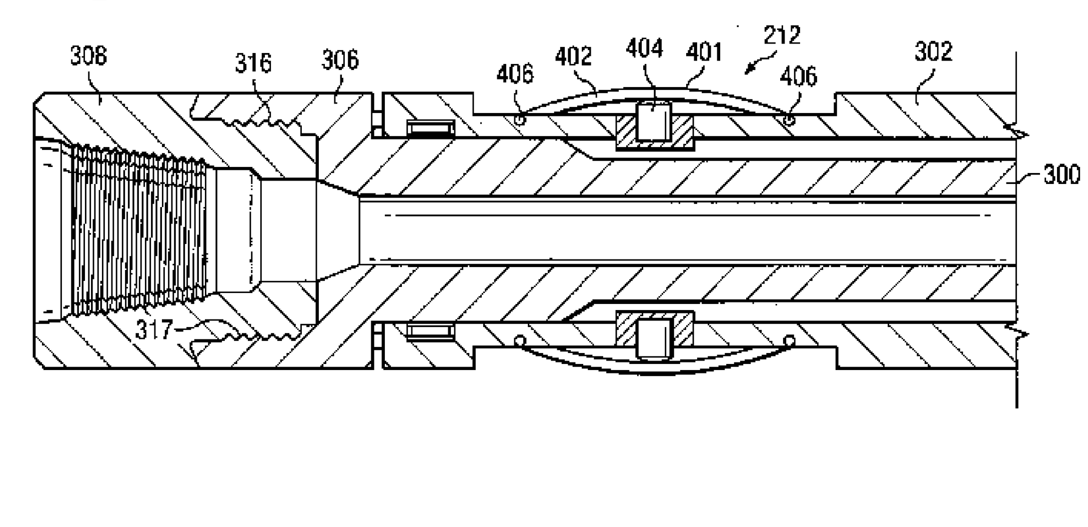
(57) **ABSTRACT**

According to one embodiment of the invention, a rotary steerable tool includes a drive shaft configured to be coupled to a drill string at an upper end thereof and configured to be coupled to a drilling tool at a lower end thereof. A middle portion of the drive shaft is disposed axially between the upper and lower ends and has a smaller diameter than each of the upper and lower ends. The drive shaft further includes a housing rotatably coupled externally to the drive shaft and at least one housing module coupled to a respective opening in the housing at an axial location corresponding to the middle portion of the drive shaft.

25 Claims, 4 Drawing Sheets





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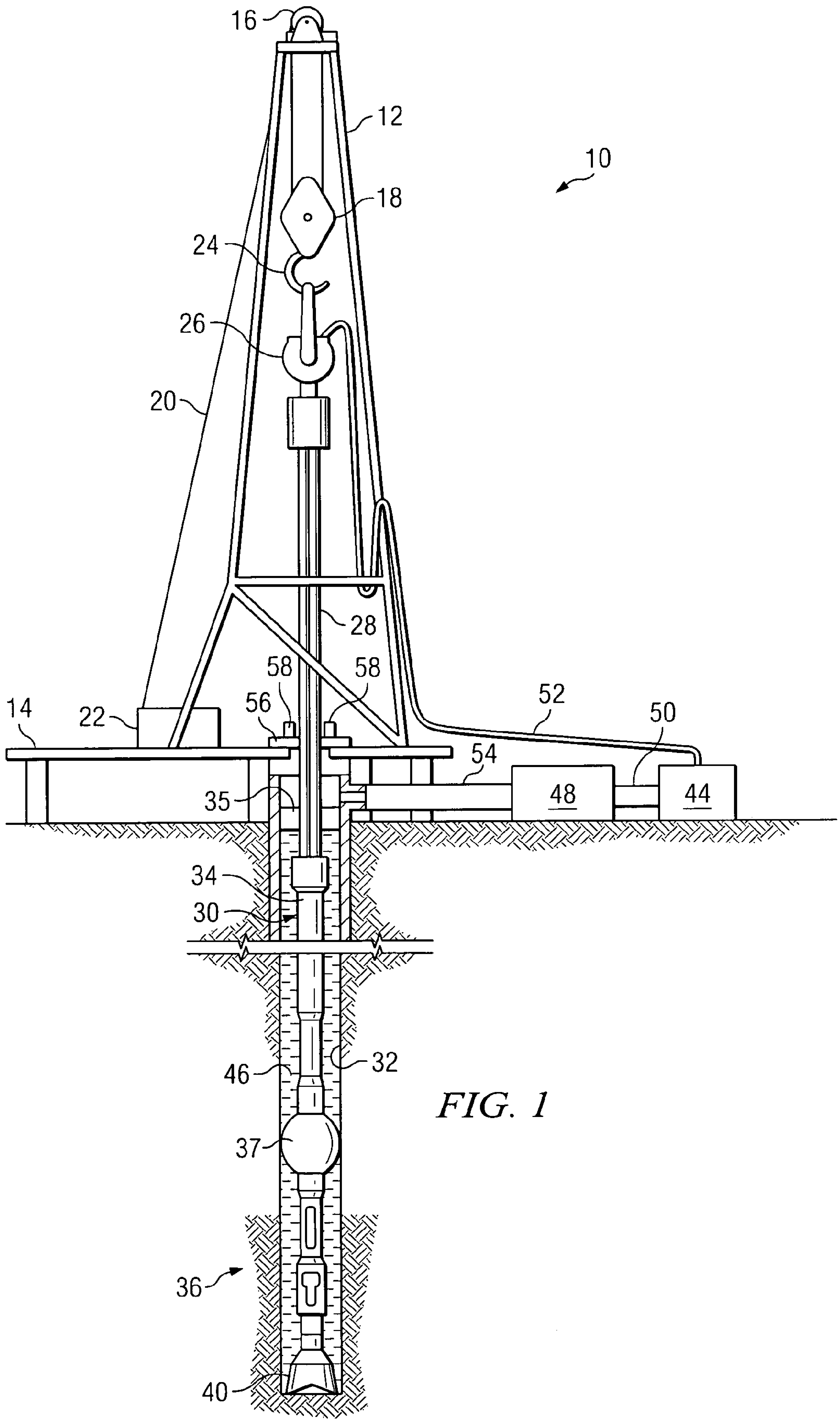
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12
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24
26
20
28
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30
46
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36
40

FIG. 1

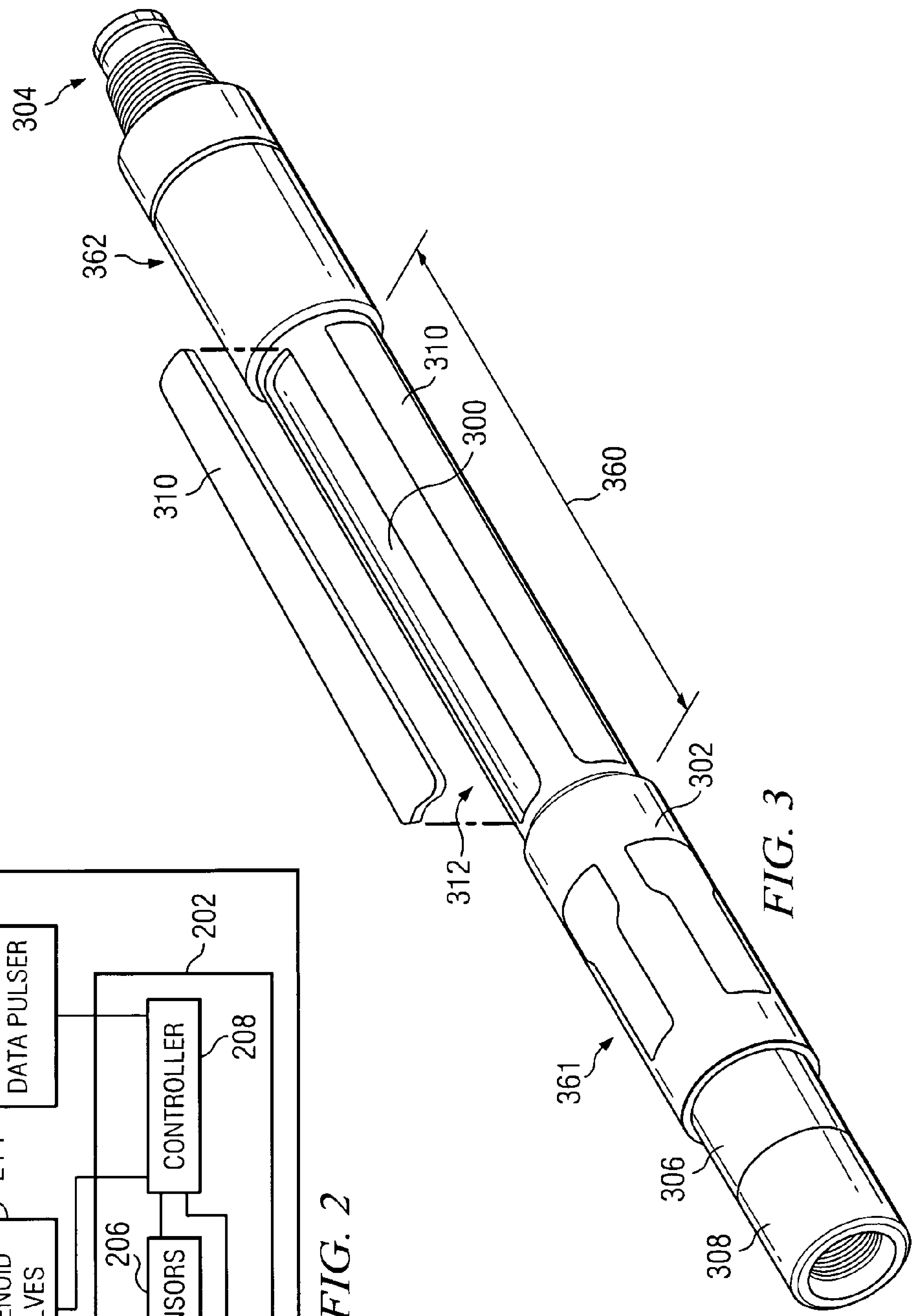
304
362
310
310
300
360
302
312
361
306
308

FIG. 3

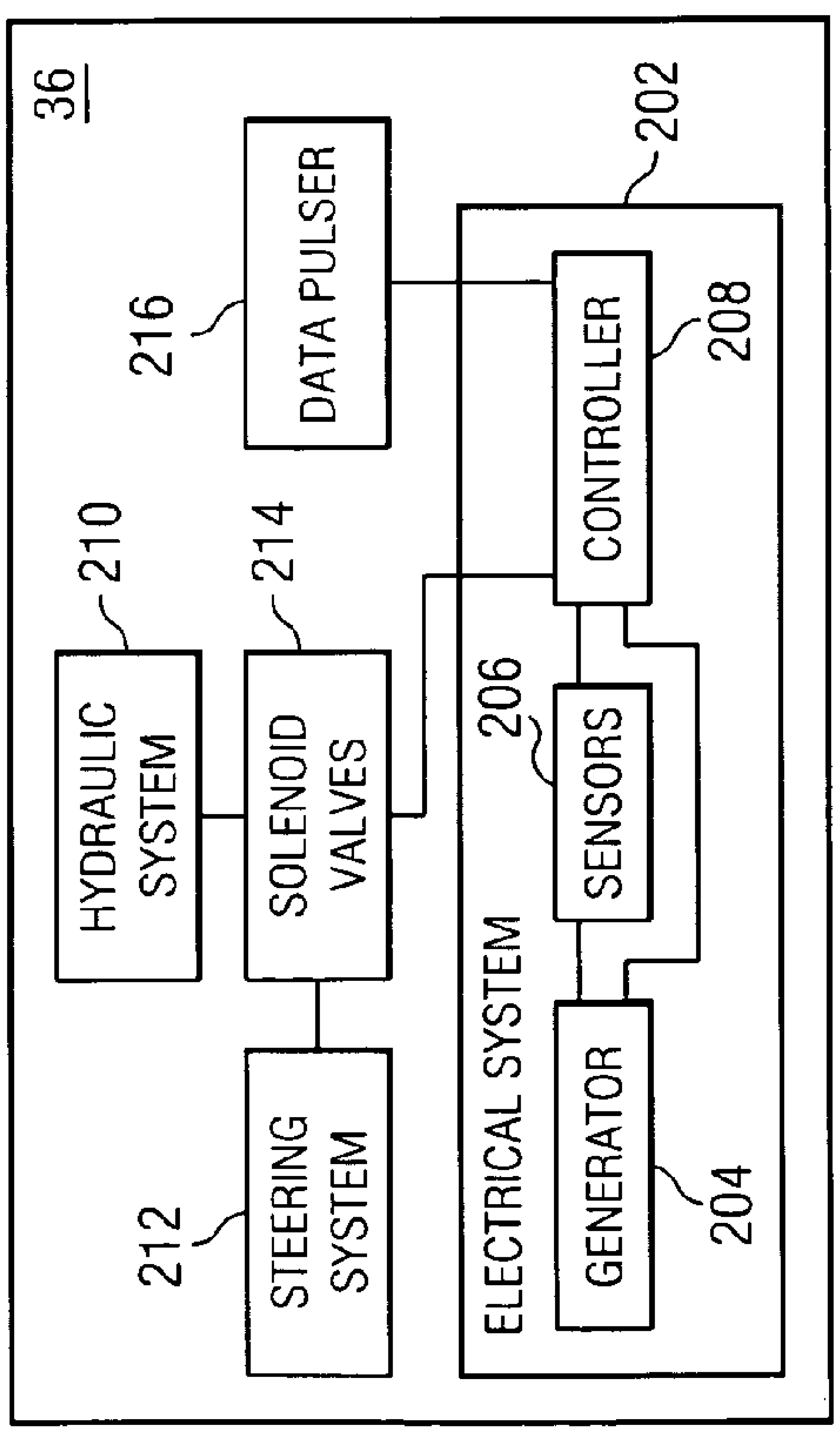
36
DATA PULSER
216
202
CONTROLLER
208
HYDRAULIC SYSTEM
210
SOLENOID VALVES
214
SENSORS
206
ELECTRICAL SYSTEM
STEERING SYSTEM
212
GENERATOR
204

FIG. 2

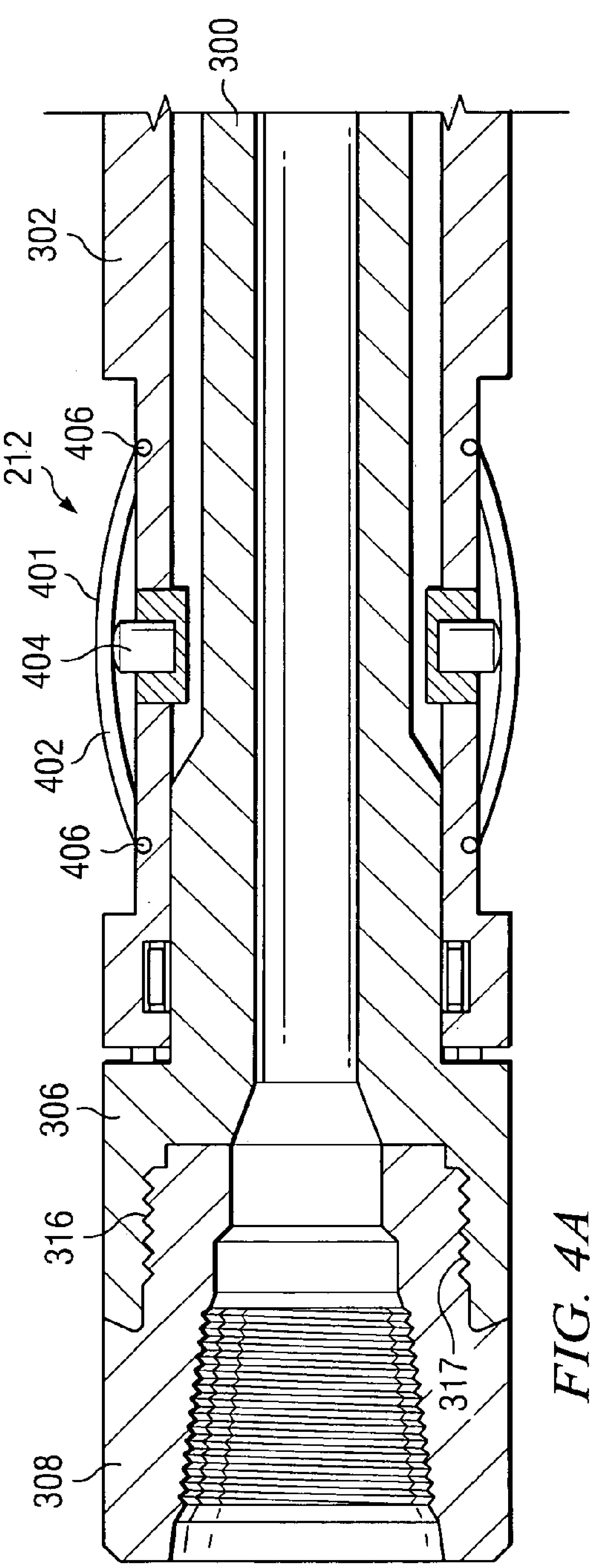
300
302
212
406
401
404
402
406
306
316
317
308

FIG. 4A

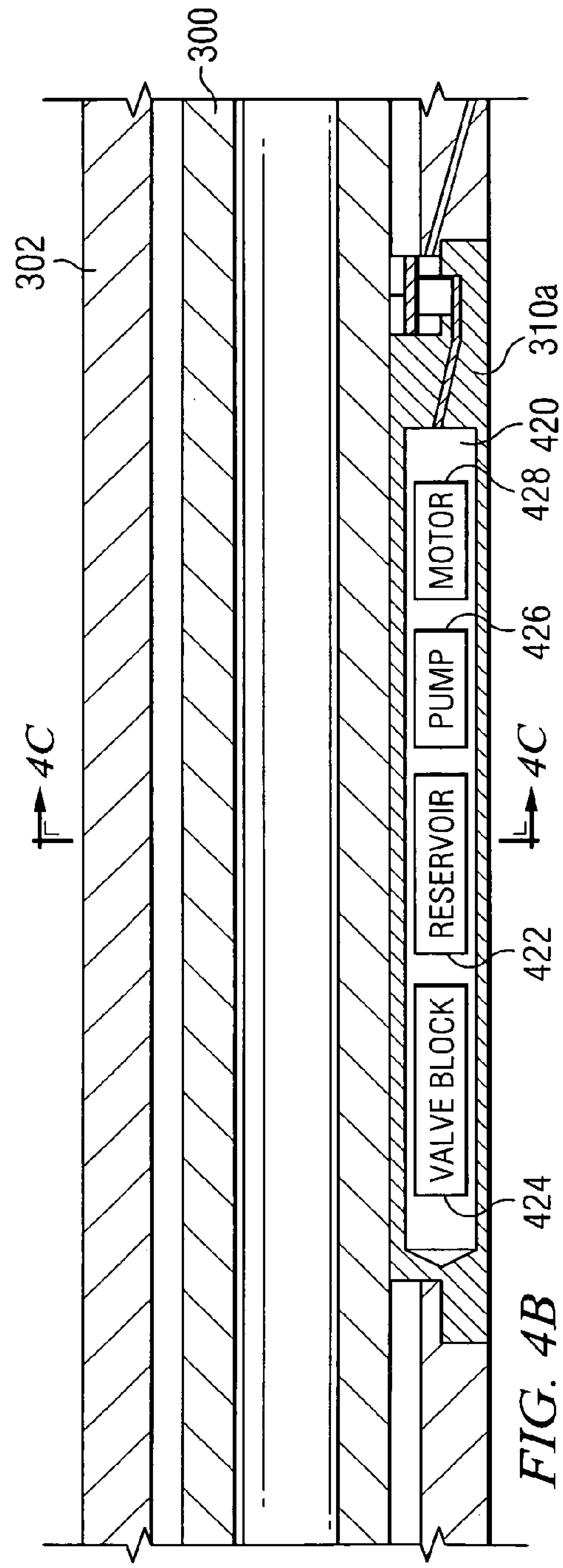
300
302
310a
420
428
MOTOR
426
PUMP
4C
4C
RESERVOIR
422
VALVE BLOCK
424

FIG. 4B

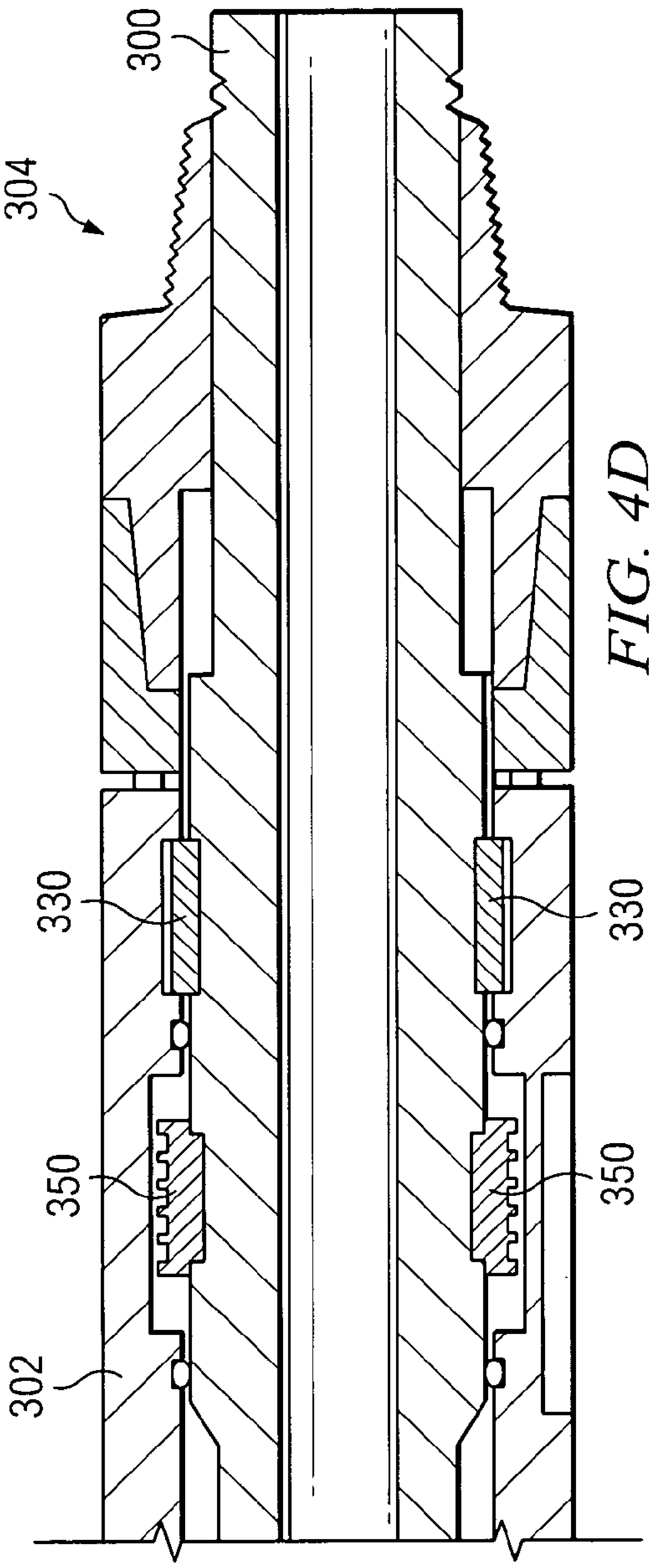
300
304
330
330
350
350
302

FIG. 4D

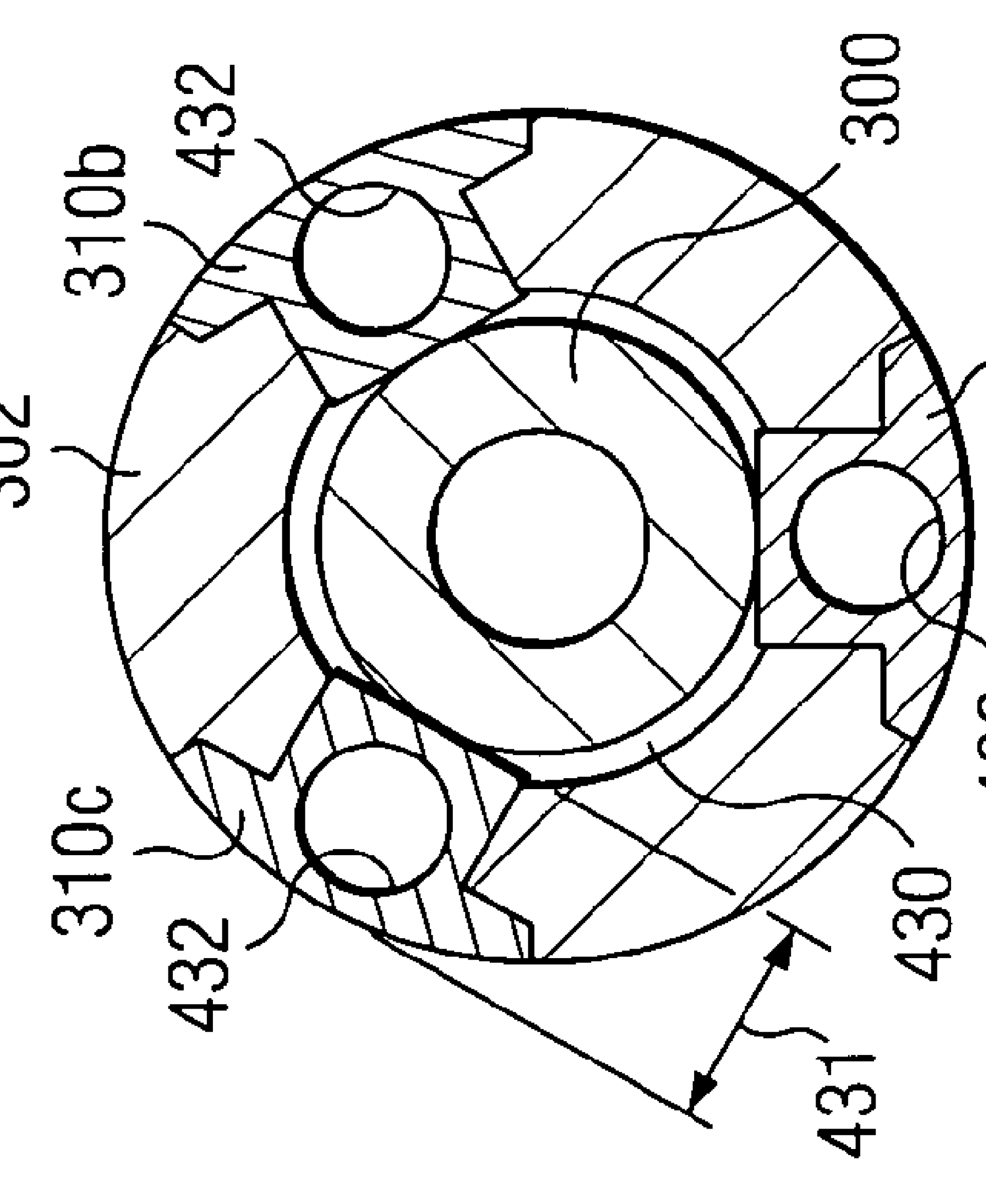
432
300
310b
310a
302
432
310c
430
432
431

FIG. 4C

MODULAR HOUSING FOR A ROTARY STEERABLE TOOL

RELATED APPLICATION

This application claims the benefit of U.S. provisional application Ser. No. 60/479,607, filed Jun. 17, 2003, entitled MODULAR HOUSING FOR A ROTARY STEERABLE TOOL.

TECHNICAL FIELD OF THE INVENTION

This invention relates generally to the field of drilling systems and, more particularly, to a modular housing for a rotary steerable tool.

BACKGROUND OF THE INVENTION

Drilling well bores in the earth, such as well bores for oil and gas wells, is an expensive undertaking. One type of drilling system used is rotary drilling, which consists of a rotary-type rig that uses a sharp drilling tool at the end of a drill string to drill deep into the earth. At the earth's surface, a rotary drilling rig often includes a complex system of cables, engines, support mechanisms, tanks, lubricating devices, and pulleys to control the position and rotation of the bit below the surface. Underneath the surface, the drilling tool is attached to a long drill string that transports drilling fluid to the drilling tool. The drilling fluid lubricates and cools the drilling tool and also-functions to remove cuttings and debris from the well bore as it is being drilled.

Directional drilling involves drilling in a direction that is not necessarily precisely vertical to access reserves. Directional drilling involves turning of the drilling tool while within the well bore. Offshore drilling often involves directional drilling because of the limited space beneath the offshore platform, although directional drilling is also vastly used onshore.

Various types of directional drilling tools exist. One type of directional drilling involves rotary steerable directional drilling, in which the drill string continues to rotate while steering takes place. Typically, a plurality of steering ribs are associated with the rotary steerable tool to facilitate the steering. The ribs are disposed outwardly from a sleeve, inside of which is disposed a rotating shaft associated with the drill string. In one type of rotary steerable tool, the outer sleeve rotates and in another the outer sleeve does not rotate. In the type in which the outer sleeve does not rotate, bearings allow relative movement between the outer sleeve and the rotating shaft. High axial and torsional forces are often encountered during this type of drilling.

SUMMARY OF THE INVENTION

According to one embodiment of the invention, a rotary steerable tool includes a drive shaft configured to be coupled to a drill string at an upper end thereof and configured to be coupled to a drilling tool at a lower end thereof. A middle portion of the drive shaft is disposed axially between the upper and lower ends and has a smaller diameter than each of the upper and lower ends. The drive shaft further includes a housing rotatably coupled externally to the drive shaft and at least one housing module coupled to a respective opening in the housing at an axial location corresponding to the middle portion of the drive shaft.

Some embodiments of the invention provide numerous technical advantages. Other embodiments may realize some, none, or all of these advantages. For example, according to one embodiment, a smaller diameter rotary steerable tool may be utilized without having to worry about breakage of the rotary steerable tool due to torsional forces. A smaller diameter rotary steerable tool, with its associated small diameter drill string, may not only be used to drill small diameter bore holes, but may be easily insertable into existing larger diameter bore holes so that new large diameter bore holes do not have to be drilled.

Other advantages may be readily ascertainable by those skilled in the art from the following figures, description, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of a drilling rig in accordance with one embodiment of the present invention;

FIG. **2** is a functional block diagram of a rotary steerable tool associated with a drill string of the drilling rig of FIG. **1** in accordance with one embodiment of the present invention;

FIG. **3** is a perspective view of an example rotary steerable tool in accordance with one embodiment of the present invention; and

FIGS. **4**A through **4**D are various cross-sectional views of the rotary steerable tool of FIG. **3** in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION

The following description is directed to a rotary steerable tool associated with a drill string. In one embodiment, a rotary steerable tool facilitates, among other things, more efficient and cost-effective drilling of well bores, especially small diameter well bores. In one embodiment of the, invention, as described below, a smaller diameter rotary steerable tool may be utilized without having to worry about drilling problems, such as breakage of the rotary steerable tool, due to torsional forces encountered when drilling. This is facilitated, in one embodiment, by modular housing that allows the drive shaft of the rotary steerable tool to have a smaller diameter at a location of the electronics and hydraulics used for drilling.

FIG. **1** illustrates a drilling rig **10** in accordance with one embodiment of the present invention. In this embodiment, rig **10** is a conventional rotary table/kelley drive; however, the present invention contemplates other suitable drive devices for drilling rigs, such as top drive, power swivel, and down hole motor. Non-land rigs, such as jack up rigs, semi-submersibles, drill ships, mobile offshore drilling units (MODUs), and other suitable drilling systems that are operable to bore through the earth to resource-bearing or other geologic formations are also useful with the invention.

In the illustrated embodiment, rig **10** includes a mast **12** supported above a rig floor **14**. A lifting gear associated with rig **10** includes a crown block **16** mounted to mast **12** and a travelling block **18**. Crown block **16** and travelling block **18** are coupled by a cable **20** that is driven by draw works **22** to control the upward and downward movement of travelling block **18**.

Travelling block **18** carries a hook **24** from which is suspended a swivel **26**. Swivel **26** supports a kelley **28**, which in turn supports a drill string, designated generally by the numeral **30**, in a well bore **32**. A blow out preventor (BOP) **35** is positioned at the top of well bore **32**. Drill string **30** may be held by slips **58** during connections and rig-idle situations or at other appropriate times.

Drill string **30** includes a plurality of interconnected sections of drill pipe **34**, one or more stabilizers **37**, a rotary steerable tool **36**, and a rotary drilling tool **40**, which may be a drill bit. Drill pipe **34** may be any suitable drill pipe having any suitable diameter and formed from any suitable material. Rotary steerable tool **36**, which is described in greater detail below in conjunction with FIGS. **2** through **4**D, generally functions to control the drilling direction of drilling tool **40**. Rotary drilling tool **40** functions to bore through the earth when drill string **30** is rotated and weight is applied thereto. Drill string **30** may include different elements or more or fewer elements than those illustrated depending on the type of drilling system. For example, drill string **30** may also include drill collars, measurement well drilling (MWD) instruments, and other suitable elements and/or systems.

Mud pumps **44** draw drilling fluid, such as mud **46**, from mud tanks **48** through suction line **50**. A "mud tank" may include any tank, pit, vessel, or other suitable structure in which mud may be stored, pumped from, returned to, and/or recirculated. Mud **46** may include any suitable drilling fluids, solids or mixtures thereof. Mud **46** is delivered to drill string **30** through a mud hose **52** connecting mud pumps **44** to swivel **26**. From swivel **26**, mud **46** travels through drill string **30** and rotary steerable tool **36**, where it exits drilling tool **40** to scour the formation and lift the resultant cuttings through the annulus to the surface. At the surface, mud tanks **48** receive mud **46** from well bore **32** through a flow line **54**. Mud tanks **48** and/or flow line **54** include a shaker or other suitable device to remove the cuttings.

Mud tanks **48** and mud pumps **44** may include trip tanks and pumps for maintaining drilling fluid levels in well bore **32** during tripping out of hole operations and for receiving displaced drilling fluid from the well bore **32** during tripping-in-hole operations. In a particular embodiment, the trip tank is connected between well bore **32** and the shakers. A valve is operable to divert fluid away from the shakers and into the trip tank, which is equipped with a level sensor. Fluid from the trip tank may then be directly pumped back to well bore **32** via a dedicated pump instead of through the standpipe.

Drilling is accomplished by applying weight to drilling tool **40** and rotating drill string **30**, which in turn rotates drilling tool **40**. Drill string **30** is rotated within well bore **32** by the action of a rotary table **56** rotatably supported on the rig floor **14**. Alternatively, or in addition, a down hole motor may rotate drilling tool **40** independently of drill string **30** and the rotary table **56**. As previously described, the cuttings produced as drilling tool **40** drills into the earth are carried out of well bore **32** by mud **46** supplied by pumps **44**. To direct or "steer" drilling tool **40** in a desired direction, drill string **30** includes rotary steerable tool **36** adjacent to drilling tool **40**.

FIG. **2** is a functional block diagram of rotary steerable tool **36** illustrating some of the components of rotary steerable tool **36** in accordance with one embodiment of the present invention. As illustrated, rotary steerable tool **36** includes an electrical system **202**, a hydraulic system **210**, a steering system **212**, solenoid valves **214**, and a data pulser **216**.

Electrical system **202** includes a generator **204**, a plurality of sensors **206**, and a controller **208**. Generally, generator **204** provides the electrical power for rotary steerable tool **36**. A separate power source (not shown) may also be provided in addition to generator **204** to provide additional power or to provide backup power to rotary steerable tool **36**. Generator **204** may also be used to provide power to other elements, components, or systems associated with either rotary steerable tool **36** or drill string **30**.

Sensors **206** may include any suitable sensors or sensing systems that are operable to monitor, sense, and/or report characteristics, parameters, and/or other suitable data associated with rotary steerable tool **36**, drilling tool **40**, or the conditions within well bore **32**. For example, sensors **206** may include conventional industry standard triaxial magnetometers and accelerometers for measuring inclination, azimuth, and tool face parameters. The sensed characteristics, parameters, and/or data is typically automatically sent to controller **208**; however, sensors **206** may send the characteristics, parameters, and/or data to controller **208** in response to queries by controller **208**.

Generally, controller **208** provides the "brains" for rotary steerable tool **36**. Controller **208** is any suitable down hole computer or computing system that is operable to receive sensed characteristics or parameters from sensors **206** and to communicate the sensed characteristics or parameters to the surface so that drilling personnel may monitor the drilling process on a substantially real-time basis, if so desired. The data communicated to the surface may be processed by controller **208** before communication to the surface or may be communicated to the surface in an unprocessed state. Controller **208** communicates data to the surface using any suitable communication method, such as controlling data pulser **216**.

Data pulser **216** may be any suitable transmission system operable to generate a series of mud pulses in order to transmit the data to the surface. Typically, mud pulses are created by controlling the opening and closing of a valve associated with data pulser **216**, thereby allowing a small volume of mud to divert from inside drill string **30** into an annulus of well bore **32**, bypassing drilling tool **40**. This creates a small pressure loss, known as a "negative pulse" inside drill string **30**, which is detected at the surface as a slight drop in pressure. The controlling of the valve associated with data pulser **216** is controlled by controller **208**. In this manner, data may be transmitted to the surface as a coded sequence of pressure pulses. Alternate types of pulses that may be used momentarily restrict mud flow inside the pipe. This type is referred to as a "positive pulse."

Hydraulic system **210** generally functions to provide hydraulic pressure to steering system **212** so that arched spring members associated with steering system **212** may be actuated in a predetermined manner to facilitate the steering of drilling tool **40**. The arched spring members, which are described in greater detail below in conjunction with FIG. **4**A, are part of steering system **212** along with associated pistons that function to "push out" a respective arched spring member when a respective solenoid valve **214** is opened by electrical system **202**. Solenoid valves **214** may be any suitable solenoid valves that are operable to allow hydraulic fluid to pass through hydraulic passages for the purpose of actuating arched spring members via pistons. Controller **208** may function to control the opening and closing of solenoid valves **214**.

FIG. **3** is a partially exploded perspective view of an example rotary steerable tool **36** in accordance with one embodiment of the present invention. In the illustrated embodiment, rotary steerable tool **36** includes a rotating shaft **300**, generally referred to as a "drive shaft," rotatably coupled within a non-rotating housing **302**, a head end **304**, a box end **306**, and a saver sub **308**.

Rotating shaft **300** is a hollow shaft having any suitable diameter and formed from any suitable material that is coupled to drill pipe **34** via head end **304** and coupled to drilling tool **40** (not explicitly shown) via saver sub **308**. In one embodiment, rotating shaft **300** is formed from non-magnetic alloy, such as Monel or Inconel, so that magnetometers used with rotary steerable tool **36** operate properly.

According to one embodiment of the invention, rotating shaft **300** has a variable diameter along its length with its smallest diameter being associated with an intermediate portion of rotating shaft **300**. As shown and described in more detail below in conjunction with FIGS. **4**A through **4**D, in one embodiment, a middle portion **360** of rotating shaft **300** has a smaller diameter than end portions **361**, **362** of rotating shaft **300**. This facilitates a smaller diameter rotary steerable tool **36** because, as described in more detail below, housing **302** may have a smaller diameter if middle portion **360** of rotating shaft has a smaller diameter. One reason the end portions **361**, **362** of rotating shaft **300** may have a larger diameter than middle portion **360** is so that drilling problems, such as breakage of rotary steerable tool **36**, due to torsional forces encountered during drilling may be avoided.

Housing **302** houses many of the components of electrical system **202**, hydraulic system **210**, steering system **212**, and data pulser **216**, as well as solenoid valves **214**, as described in greater detail below in conjunction with FIGS. **4**A and **4**B. Housing **302** may be formed from any suitable material, usually non-magnetic. Some components associated with housing **302** may be adversely affected by magnetic fields; therefore, the material used to house these elements, such as the elements of electrical system **202**, are preferably made of a non-magnetic material, such as Monel or other suitable non-magnetic material.

As described above, a smaller diameter housing **302** may result by providing middle portion **360** of rotating shaft **300** with a smaller diameter than end portions **361**, **362** of rotating shaft **300**. Solely as examples, housing **302** may have an outside diameter of approximately 4¾ inches or approximately 3½ inches. The smaller diameter housing **302** means that there is less space for such elements as the components of electrical system **202**, hydraulic system **210**, steering system **212**, and solenoid valves **214**. Therefore, according to the teachings of one embodiment of the invention, housing **302** includes a set of housing modules **310** that fit within respective openings **312** in the wall of housing **302**, as illustrated in FIG. **3**.

Housing modules **310**, which are described in greater detail below in conjunction with FIGS. **4**B and **4**C, generally function to house the components of electrical system **202**, hydraulic system **210**, solenoid valves **214**, and other suitable components that allow rotary steerable tool **36** to be utilized for directional drilling. For example, the directional sensing electronics may be disposed within one of the housing modules **310**, while the hydraulic system and related components may be disposed within another of the housing modules **310**. Any suitable number of housing modules **310** may be utilized around the circumference of housing **302**, and they may be spaced around the circumference of housing **302** in any suitable manner. In one embodiment, three housing modules **310** are utilized and substantially equally spaced about the circumference of housing **302**. Housing modules **310** may couple to openings **312** in any suitable manner, and are located on housing **302** at an axial location that corresponds to the middle portion **360** of rotating shaft **300**.

FIGS. **4**A-**4**D are various cross-sectional views of rotary steerable tool **36** in accordance with one embodiment of the present invention.

FIG. **4**A illustrates box end **306**, saver sub **308**, and steering system **212** associated with housing **302**. FIG. **4**B illustrates housing modules **310** disposed within openings **312** within the wall of housing **302** and intermediate portion of rotating shaft **300** disposed within housing **302**. FIG. **4**C illustrates a circumferential cross-sectional view of housing modules **310** and their orientation. FIG. **4**D illustrates head end **304** of rotating shaft **300**.

Referring to FIG. **4**A, box end **306** couples to rotating shaft **300** in any suitable manner. In a particular embodiment, box end **306** is formed integral with rotating shaft **300**. Box end **306** has internal threads **316** that function to accept external threads **317** of saver sub **308** in order to couple saver sub **308** to box end **306**. Saver sub **308** functions to couple drilling tool **40** thereto and protects box end **306** from damage arising from repeated threading/unthreading of drilling tool **40**.

Steering system **212**, according to one embodiment, includes a spring member **402** having a bearing surface **401**; a pair of mounting pins **406** coupling spring member **402** to housing **302**, and a piston **404**. Generally, steering system **212** functions to steer drilling tool **40** in a desired direction when arched spring member **402** of steering system **212** is actuated radially by a respective piston **404** such that bearing surface **401** applies a force to the wall of well bore **32**. Although bearing surface **401** may have any suitable profile, including a flat surface, bearing surface **401** preferably has a curved profile that substantially matches the profile of the wall of well bore **32** so that an evenly distributed load may be applied thereto.

Spring member **402** is coupled to housing **302** via pins **406**. In one embodiment, either one or both pins **406** are disposed within slots formed within the wall of housing **302** to allow for axial movement when piston **404** is actuated. However, spring member **402** may be coupled to housing **302** in other suitable manners.

In one embodiment, there are four steering systems **212** spaced approximately an equal circumferential distance apart around housing **302**; however, any number of steering systems **212** may be used.

Also illustrated in FIG. **4**A is a transition of rotating shaft **300** to a smaller diameter. This allows space for pistons **404** and their associated fluid conduits (not explicitly shown). In addition, as described in more detail below in conjunction with FIG. **4**B, this smaller diameter allows space for housing modules **310**.

Referring to FIG. **4**B, a particular housing module **310** is illustrated. This particular housing module **310***a* is shown to be housing components of hydraulic system **210** via a pressure barrel **420**. Any suitable pressure barrel having any suitable configuration may be utilized to house and protect the components therein. Pressure barrel **420** may be sealed from the environment on the outside of rotary steerable tool **36** by any suitable number and type of seals.

In the illustrated embodiment, components of hydraulic system **210** include a hydraulic fluid reservoir **422**, a valve block **424**, a hydraulic pump **426**, and a motor **428** to drive the pump **426**. Reservoir **422** houses any suitable hydraulic fluid used to translate pistons **404** for the purpose of actuating spring members **402** in order to steer drilling tool **40**, as described above. Valve block **424** facilitate the transportation of hydraulic fluid from reservoir **422** to pistons **404** via suitable hydraulic passages, which may be formed in the wall of housing **302** in any suitable manner and in any suitable location. Hydraulic pump **426** is used to pressurize the hydraulic fluid so there is adequate force exerted on the underside of pistons **404** in order to translate them.

Although not illustrated in the cross-sectional view of FIG. **4**B, other housing modules **310** may house components of electrical system **202**. These may include a generator, sensors, and a controller. As described above, generator **204** is used to provide power to solenoid valves **214**, sensors **206**, and controller **208**. For example, at the appropriate time, controller **208** directs a particular solenoid valve **214** to open so that pressurized hydraulic fluid from reservoir **422** may translate a particular piston **404** in order to actuate a particular spring member **402** for the purpose of steering drilling bit **40** in a desired direction.

Sensors **206**, as described above, operate to sense various characteristics and parameters of the drilling process so that data that is indicative of the sensed characteristics and parameters may be transmitted to the surface in order to effectively control the drilling process form the surface. The measurements from the sensors also cause the controller to operate steering system **212** to steer drilling tool **40** along a pre-programmed trajectory.

Referring to FIG. **4**C, a circumferential cross-section at an intermediate portion of rotating shaft **300** and housing **302** is illustrated. Also illustrated are example housing module **310***a*, **310***b*, and **310***c*. In the illustrated embodiment, modules **310** are substantially equally spaced around the circumference of housing **302**; however, other suitable spacing may be utilized.

Also illustrated in FIG. **4**C, is an annular space **430** existing between rotating shaft **300** and housing **302**. Annular space **430** accounts for the larger diameter at the end portions **361**, **362** of rotating shaft **300** so that rotating shaft **300** may be inserted into housing **302**. Annular space **430** also allows housing modules **310** to extend beyond an inside surface of housing **302**. In other words, a depth **431** of housing modules **310** defines a minimum internal diameter smaller than a minimum internal diameter defined by housing **302**. The spacing between the ends of housing modules **310** and outside surface of rotating shaft **300** is typically no more than about two millimeters. Having housing modules **310** to be selectively removable from openings within the wall of housing **302** allows rotating shaft **300** to be inserted into housing **302** before the modules **310** are coupled to housing **302**. This extra length of housing modules **310** allows for more space for the hydraulic and electrical components, as discussed above.

As discussed above in conjunction with FIG. **4**B, pressure barrels are used to house and protect various components from the environment. These pressure barrels are, in one embodiment, round barrels that fit within openings **432** within housing modules **310**, as shown in FIG. **4**C.

Referring to FIG. **4**D, head end **304** may be coupled to drill pipe **34** in any suitable manner. Also illustrated in FIG. **4**D is a pair of slip rings **330** that function to transfer electrical power between rotating shaft **300** and non-rotating housing **302**. Any suitable type and number of slip rings may be utilized. A pair of seals, such as Kalsi seals, may be utilized on either side of slip rings **330**. One of these seals may be utilized to act as a compensating piston.

To drill well bore **32**, weight is applied to drilling tool **40** and drilling commences by rotating drill pipe **34**, which rotates head end **304**, rotating shaft **300**, box end **306**, saver sub **308**, and drilling tool **40** (not explicitly shown). Concurrently, drilling fluid, such as mud **46**, is circulated down through drill pipe **34**, rotating shaft **300**, and saver sub **308** before exiting drilling tool **40** and returning to the surface in the annulus formed between the wall of well bore **32** and the outside surfaces of rotary steerable tool **36** and drill pipe **34**. Rotating shaft **300** is able to rotate within housing **302** by utilizing one or more bearings **350**. Any suitable bearings **310** may be utilized, such as roller bearings, journal bearings, and the like.

Although embodiments of the invention and their advantages are described in detail, a person of ordinary skill in the art could make various alterations, additions, and omissions without departing from the spirit and scope of the present invention as defined by the appended claims.

What is claimed is:

1. A rotary steerable tool, comprising:
- a drive shaft comprising a lower end, an upper end and a middle portion, wherein the lower end, the upper end, and the middle portion of the drive shaft are formed as a single component to have no separable subcomponents, the drive shaft configured to be coupled to a drill string at the upper end thereof, the drive shaft configured to be coupled to a drilling tool at the lower end thereof, the middle portion of the drive shaft disposed axially between the upper and lower ends having a smaller diameter than each of the upper and lower ends;
- a housing rotatably coupled externally to the drive shaft; and
- at least one housing module coupled to a respective opening in the housing at an axial location corresponding to the middle portion of the drive shaft.

2. The rotary steerable tool of claim **1**, wherein a depth of the at least one housing module defines a minimum internal diameter smaller than a minimum internal diameter defined by the housing.

3. The rotary steerable tool of claim **1**, further comprising:
- directional sensing electronics disposed within the at least one housing module; and
- a hydraulic system disposed within at least one additional housing module, the at least one additional housing module disposed in a corresponding opening in the housing disposed axially corresponding to the middle portion of the drive shaft.

4. The rotary steerable tool of claim **1**, further comprising a plurality of biasing mechanisms coupled to the housing, each biasing mechanism configured to steer the steering tool when actuated by a piston.

5. The rotary steerable tool of claim **4**, wherein each biasing mechanism comprises an arched spring member coupled to the housing by a pinned connection and wherein the piston engages an underside of the arched spring member.

6. The rotary steerable tool of claim **1**, wherein an outside diameter of the housing is approximately 4¾ inches.

7. The rotary steerable tool of claim **1**, wherein an outside diameter of the housing is approximately 3½ inches.

8. The rotary steerable tool of claim **1**, further comprising three housing modules substantially equally spaced about the circumference of the housing, each of the three modules disposed in a corresponding opening in the housing at an axial position corresponding to the middle portion of the drive shaft.

9. The rotary steerable tool of claim **1**, wherein a clearance between each housing module and an outside surface of the drive shaft is at most about two millimeters.

10. A system for housing a drive shaft of a rotary steerable tool, comprising:
- a housing rotatably coupled externally to the drive shaft, the drive shaft comprising a lower axial end portion, an upper axial end portion and a middle portion, wherein the lower axial end portion, the upper axial end portion and the middle portion are formed as a single component to have no separable subeomponents, the housing

comprising a plurality of axially extending openings formed in a wall of the housing;

a plurality of housing modules each coupled to a respective one of the openings at an axial location corresponding to the middle portion of the drive shaft, the middle portion having a diameter smaller than a diameter of axial end portions of the drive shaft, each of the housing modules extending radially inward beyond an inside surface of the wall of the housing within an annular space between the housing and the drive shaft.

11. The system of claim **10**, further comprising:

directional sensing electronics disposed within one of the housing modules; and

a hydraulic system disposed within another one of the housing modules.

12. The system of claim **11**, further comprising a plurality of biasing mechanisms coupled to the housing, each biasing mechanism configured to steer the steering tool when actuated by a piston.

13. The system of claim **12**, wherein each biasing mechanism comprises an arched spring coupled to the housing by a pinned connection and wherein the piston engages an underside of the arched spring.

14. The system of claim **10**, wherein an outside diameter of the housing is approximately 4¾ inches.

15. The system of claim **10**, wherein an outside diameter of the housing is approximately 3½ inches.

16. The system of claim **10**, wherein a diameter of a circle that can fit inside the inside surfaces of the housing modules is smaller than an inside diameter of the housing.

17. The system. of claim **10**, wherein the openings are substantially equally spaced about the circumference of the housing.

18. The system of claim **10**, wherein a clearance between an inside surface of each housing module and an outside surface of the drive shaft is at most about two millimeters.

19. A rotary steerable tool, comprising:

a variable diameter drive shaft comprising a lower end, an upper end and an intermediate portion, wherein the lower end, the upper end, and the intermediate portion of the drive shaft are formed as a single component to have no separable subcomponents, the drive shaft having its smallest diameter located along the intermediate portion of the drive shaft;

a housing rotatably coupled externally to the drive shaft, the housing comprising a plurality of axially extending openings formed in the housing proximate the intermediate portion of the drive shaft; and

a set of housing modules configured to fit within respective ones of the axially extending openings, each housing module extending radially inward beyond an inside surface of the housing within an annular space between the housing and the drive shaft.

20. The rotary steerable tool of claim **19**, further comprising:

directional sensing electronics disposed within one of the housing modules; and

a hydraulic system disposed within another of the housing modules.

21. The rotary steerable tool of claim **19**, further comprising a plurality of biasing mechanisms coupled to the housing, each biasing mechanism configured to steer the steering tool when actuated by a piston.

22. The rotary steerable tool of claim **21**, wherein each biasing mechanism comprises an arched spring member coupled to the housing by a pinned connection and wherein the piston engages an underside of the arched spring member.

23. The rotary steerable tool of claim **19**, wherein an outside diameter of the housing is selected from the group consisting of approximately 4¾ inches and approximately 3½ inches.

24. The rotary steerable tool of claim **19**, wherein the axially extending openings are substantially equally spaced about the circumference of the housing.

25. The rotary steerable tool of claim **19**, wherein a clearance between an inside surface of each housing module and an outside surface of the drive shaft is at most about two millimeters.

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